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ANALYSIS DESIGN TUNNEL VERTICAL AXIS OCEAN CURRENT TURBINE USING SOLIDWORKS COMPUTATIONAL FLUID DYNAMICS (CFD)

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Abstract
Development of new renewable energy in the marine power generation sector is one of the innovative solutions in producing electrical energy in a sustainable and environmentally friendly manner. However, the speed of ocean currents in Indonesia is relatively low, ranging from 0.1 m/s to 1.5 m/s. Therefore, technology is needed to increase the speed of ocean currents so that the results are more efficient. The purpose of this research is to make a vertical axis ocean current turbine tunnel construction design to increase the speed of ocean currents. This study uses literature study methods and experimental research methods, simulations carried out on the construction of tunnels of marine current power plants using SolidWorks Computational Fluid Dynamics (CFD) software. In this study, the results of increasing the speed of ocean currents after the current entered the tunnel construction were obtained. At the speed of the ocean current of 1.0 m/s, the sea current increases to 1.7 m/s, while at the speed of the sea current of 1.5 m/s it increases to 2.6 m/s. This study shows that the use of tunnels can make the flow of ocean currents more uniform with a reynold number of 100.250 at a sea current speed of 1.0 m/s and 150.375 at a sea current speed of 1.5 m/s, because the reynold number is less than 2000, it can be concluded that the type of flow contained in the tunnel is a type of laminer fluid flow.

Keywords: *Tunnel, vertical axis ocean current turbine, computational fluid dynamics (CFD)*

1. Introduction

Energy availability is an important issue that is focused on three main goals, namely economic, ecological and social development of the community as well as an effort to support RE-BID (Renewable Energy Based on Indistrial Development). The use of new and renewable energy as an energy source is the best solution in providing energy. [1]

Indonesia is one of the countries with the most potential in implementing marine power plants. Because two-thirds of Indonesia's territory is the ocean, and all of it has a huge potential to produce marine energy. As an archipelagic country, with the potential for thousands of straits to be used as a source of ocean currents as a source of electrical energy. Electricity is generated from the rotor of a turbine that rotates due to the flow force of the ocean current. [2]

The increase in energy demand is in line with rapid population growth and the limited available fossil energy resources resulting in the need to develop new and renewable energy technologies, one of which is ocean current energy. The installation of a marine current turbine is needed as a device to convert current energy into electricity. However, the use of ocean current energy as a power plant or Marine Current Power Plant in Indonesia faces several obstacles, especially due to the limited national capacity for mastery of marine energy technology [3].

Based on data from the Ministry of Energy and Mineral Resources, sea currents in Indonesian waters are generally less than 1.5 m/s, except in the straits between the islands in Bali, Lombok, and East Nusa Tenggara, the speed can reach 2.5 m/s to 3.4 m/s. The strongest tidal currents recorded in Indonesia are in the strait between Taliabu Island and Mangole Island in the Sula Islands, North Maluku, with a speed of 5 m/s. [4]

The inflow velocity has a non-uniform profile impacting turbine performance [5]. The turbulence characteristics of inflow from small-scale experiments and current turbine numerical models are often reported to reduce the performance efficiency of ocean current turbines

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[6]. Research was conducted using Computational Fluid Dynamics (CFD) software to determine a more uniform form of fulida flow[7]. The intensity of turbulence can affect turbine performance but, perhaps most importantly, it greatly affects the design shape of the marine current power plant [8]. It is necessary to create a channel with the function of uniformizing the flow of ocean currents to the turbine [9].

Turbines with flanged channels have been identified to provide a significant improvement in power output performance for tidal flows [10]. The effect of using augmented diffusers is more efficient compared to naked turbines [11]. Therefore, it is necessary to have a tunnel construction that functions as an increase in the speed of sea currents. However, until now, there is still a lack of studies and research on tunnel construction design on vertical axis ocean current turbines that are in accordance with Indonesia's geographical conditions.

The purpose of this study is to analyze the design of a vertical axis ocean current turbine tunnel which has a function as a tool in increasing the speed of ocean currents so that it can improve the performance of the turbine. In previous research, the design of a vertical axis ocean current turbine without using a tunnel. The use of tunnels in vertical axis ocean current turbines to get maximum and efficient results in the development of ocean current power plants. The vertical axis ocean current turbine tunnel design simulation is designed to visualize the concept and operational mechanism of this technology.

2. Eksperimental Method

Research methodology is a method or procedure that contains clear stages that are systematically arranged in the research process. Each stage or part that determines the next stage so it must be passed carefully. The research methodology used is the literature study method and the simulation research method.

Study literature method is carried out to find material that supports and is in accordance with this research material as a basic theoretical comparison material of the series made. Meanwhile, the simulation or experimental research method is research that is carried out by conducting simulations on the research object and the existence of controls. In this study, the tunnel construction design was explained, the tunnel construction testing technique was carried out until an increase in the speed of the sea current entering the tunnel was obtained.

2.1 Tools and Materials

The equipment and materials that must be prepared in the design of the construction of the vertical axis ocean current turbine tunnel require several equipment to be prepared so that the work process can run smoothly and get maximum results, the equipment is the SolidWorks Computational Fluid Dynamics application version 2018. As for the materials used, date Indonesian sea current.

2.2 Research Design

Manufacture of the construction design of this vertical axis ocean current turbine tunnel using SolidWork 2018 software. Meanwhile, to carry out software design simulation method using SolidWorks Coputational Fluid Dynamics. The design of the tunnel construction can be seen in figure 1.

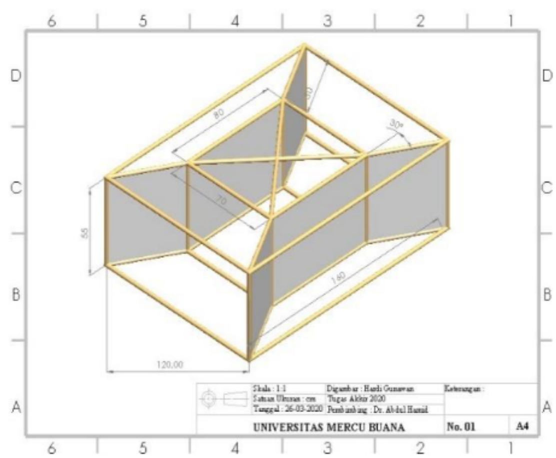

Figure 1. Tunnel

Meanwhile, the dimensions of the tunnel construction design are shown in table 1.

Table 1. Tunnel Dimensions

No.	Specifications	Size
1	Tunnel length	160 cm
2	Width in tunnel	70 cm
3	Tunnel Outer Width	120 cm
4	Tunnel height	50 cm
5	Length tunnel flow chamber	80 cm

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6	Tunnel opening angle	30°

2.3 Calculation

Calculate the Reynolds number, it is necessary to know the density, current velocity, tunnel length , and dynamic viscosity. In the construction of the tunnel this greatly influences, so the calculation uses equation one. So that Reynolds' number can be calculated as [12]:

$$Re = \frac{\rho v p}{\mu} \qquad (1)$$

Where:
ρ = density (Kg/m^3)
v = velocity (m/s)
p = long (m)
μ = viscosity dynamics (Kg/ms)

Fluid flow discharge is a formula used in calculating fluid flow velocity, To find out fluid flow discharge can use equation two, which is as follows:

$$Q = A.V \qquad (2)$$

Where:
Q = discharge flow (m3/s)
A = cross-sectional area (m2)
V = velocity (m/s)

In this study, a continuity equation was carried out to determine the flow rate of fluid in the tunnel made by the author. According to this principle, a solid, uncompressed fluid has a fixed discharge at each point along the tunnel, which means that the flow rate of the fluid will be inversely proportional to the cross-sectional area. In other words, the larger the cross-sectional area that the fluid passes through, the smaller the velocity of the fluid, and vice versa, the smaller the cross-sectional area that the fluid passes through, the faster the velocity of the fluid. The continuity equation can be formulated mathematically as follows.

$$A_1 V_1 = A_2 V_2 \qquad (3)$$

Where:
A = cross-sectional area (m^2)
1 = log in to the system
2 = out of the system boundary
V = velocity (m/s)

2.4 Tunnel Simulation

The process of simulating the tool uses SolidWorks Flow Simulation Computational Fluid Dynamics (CFD) science that studies how to predict fluid flow patterns, heat transfer, chemical reactions and other phenomena by solving mathematical equations or mathematical models. In general, the calculation process for fluid flow is completed using the equation of energy, momentum and continuity [13].

Design simulation process with current velocity used based on ocean current velocity data can be seen in table 2.

Table 2. Ocean current variation input

No.	Ocean Current	Units
1	1.0	m/s
2	1.5	m/s

Tunnel construction simulation, the parameters that will work are current speed testing, and the continuity that occurs in tunnel construction with the expected results using tunnel construction can increase the current velocity so that it can increase the efficiency of the turbine.

In this simulation stage, it consists of four stages, namely: Wizard, Setup, Solver and Result. In the wizard menu, enter the appropriate condition data to make it look like you are doing a real test.

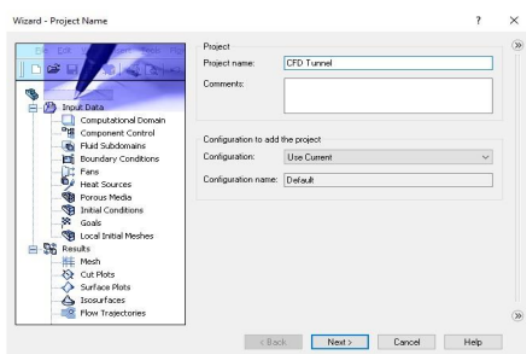

Figure 2. Wizard display

Setup stage will make several settings based on the problems to be analyzed. Simulating fluid flow at a speed variation of 1.0 m/s, and 1.5 m/s, the steps taken include setting the analysis of computational domains, rotating regions, boundary conditions, and goals to be achieved.

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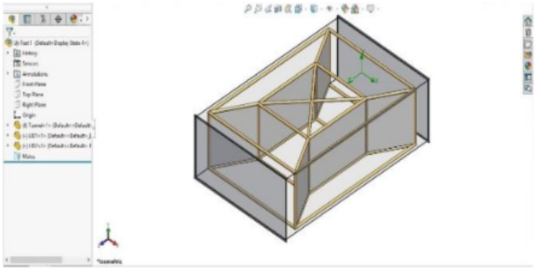

Figure 3. Setup stage

Solver stage is the numerical calculation stage by the SolidWorks Flow Simulation application, at this stage the input of the calculation formula used in the research includes the Reynolds number calculation formula, the fulida flow discharge formula and also the continuity equation formula. Next, the step is to run the tool simulation process by clicking run.

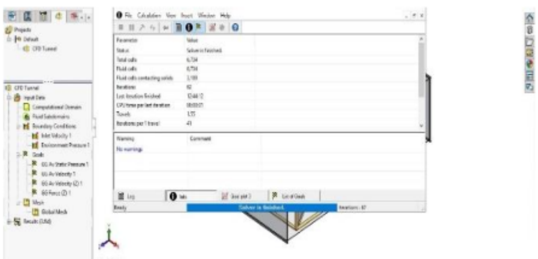

Figure 4. Solver stage

This last stage is the result stage , which is to display the results of numerical calculations based on the calculation formula that has been inputted. Some things that can be done to see the results at this stage are to display the Cut Plot, Flow Trajectories, Surface Plot, Goals, and others as needed. Goals that we already want can be moved automatically to MS excel easily.

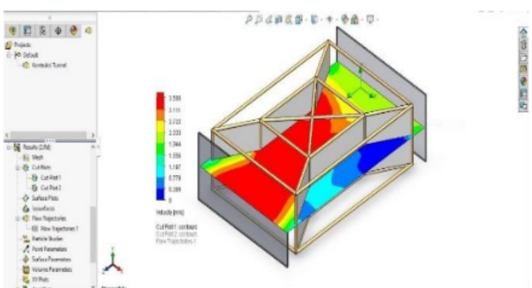

Figure 5. R*esult*

3. Results and Discussion

In this study, we will discuss the results of the simulation design design of the construction of the Tunnel construction of the ocean current power plant with the characteristics of the sea current in Indonesia using SolidWorks Computational Fluid Dynamics (CFD). The purpose of this simulation is to find out the results obtained, namely the parameters of the capability of a tunnel construction and the results of the calculations carried out [14].

From the calculation that uses the Reynolds number formula in finding the Reynolds number, the calculation results can be seen in table 3.

Table 3. Reynolds number calculation

No.	Velocity	Reynolds Number
1	1.0 m/s	100.250
2	1.5 m/s	150.375

In table 3, the value of Reynolds' number is 100.250 from a current velocity of 1.0 m/s, and 150.375 at a current velocity of 1.5 m/s. It can be concluded that the type of flow in the tunnel is a type of laminar fluid flow because the Reynolds number is less than 2000.

Calculations that use the fluid flow discharge formula in finding the discharge value of the ocean current that enters the tunnel of the vertical axis ocean current, then the calculation results can be seen in table 4.

Table 4. Fluid flow discharge calculation

No.	Velocity	Debit
1	1.0 m/s	0.63 m^3/s
2	1.5 m/s	0.91 m^3/s

While the results of the calculation in finding the value of the continuity equation, the calculation results can be seen in table 5.

Table 5. Continuity calculation

No.	Velocity	Continuity
1	1.0 m/s	1.71 m/s
2	1.5 m/s	2.57 m/s

Continuity equation shows that the incoming current speed has increased with the initial current of 1.0 m/s increasing to 1.71 m/s. Meanwhile, at the current speed of 1.5 m/s it increases to 2.57 m/s. So the vertical axis sea current turbine tunnel made can increase the speed of the sea current.

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In the context of a vertical axis ocean current turbine, this increase in the speed of the ocean current is very important because the kinetic energy of the fluid flow converted into mechanical energy by the turbine is highly dependent on the velocity of the fluid flow. An increase in flow velocity means an increase in kinetic energy, which can generate more power from the turbine.

3.2 Discussion Experimental Result Tunnel

In a previous study conducted by Matheus Nunes et al. (2020), by conducting a systematic review of augmented diffusers applied to horizontal axis ocean current turbines, it provides knowledge that augmented diffuser turbines produce high efficiency when compared to turbines that do not have diffusers [11]. Meanwhile, in the study tidal turbines with flanged channels have been identified to provide a significant improvement in the performance of the generated power output [10] The author conducted a research analysis of the design analysis of vertical axis ocean current turbine tunnel construction with 3-dimensional simulation using SolidWorks Computational Fluid Dynamics (CFD), to find out how the appropriate design concept and also its influence in increasing the speed of ocean currents. In contrast to the research conducted by Roman Gabl et al. (2022), they made a 2-dimensional simulation with a cross flow turbine venturi design [15]. The following are *the goals* obtained from the simulation of a *vertical axis ocean current turbine* tunnel.

The results of the tunnel construction simulation with a current velocity of 1.0 m/s from the results of the Computational Fluid Dynamic (CFD) simulation of tunnel construction are obtained the cut-plot velocity shown in Figure 6.

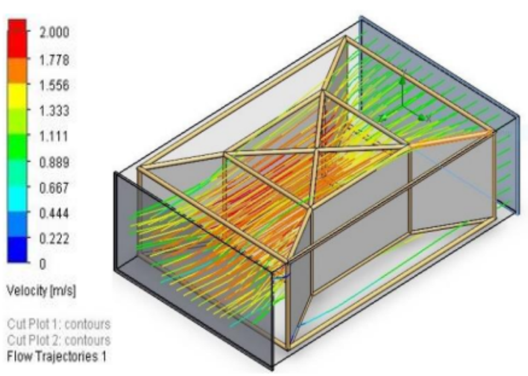

Figure 6. *Cut-plot velocity (m/s)* V 1,0 m/s

The vertical axis ocean current turbine tunnel simulation shows an increase in the speed of the ocean current after entering the tunnel construction. At first, the ocean current had a speed of 1.0 m/s with the green flow area in the simulation image. After the ocean current enters the tunnel body in the middle position, the increase in current speed is increasingly visible with the orange area, the current speed increases to 1.8 m/s. This increase reflects a change in the cross-sectional area of the flow, in accordance with the principle of the continuity equation, which states that the volumetric flow rate must remain constant. Thus, when the cross-sectional area decreases in the tunnel, the current velocity must increase to maintain the same flow rate. The results of this simulation show the effectiveness of the tunnel design in increasing the speed of ocean currents, which has the potential to improve the performance of vertical axis ocean current turbines placed in them.

The methodology used to calculate the increase in ocean current velocity through tunnel construction involves the use of continuity equations as well as other fluid mechanics concepts. The first step is to define the system and the assumptions used, such as the initial cross-sectional area and initial current velocity, as well as the final cross-sectional area and final current velocity.

The results of the tunnel construction simulation with a current velocity of 1.5 m/s from the results of the Computational Fluid Dynamic (CFD) simulation of tunnel construction obtained the cut-plot velocity shown in Figure 7.

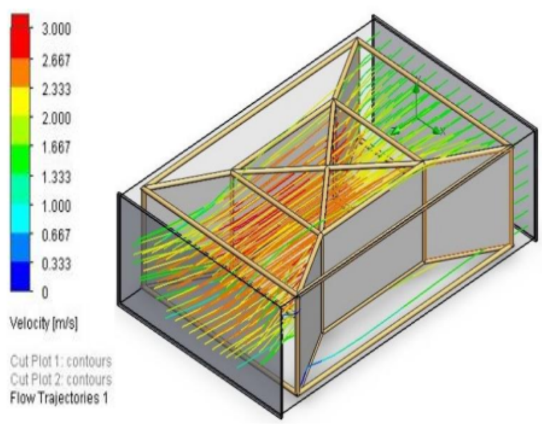

Figure 7. *Cut-plot velocity (m/s)* V 1,5 m/s

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Simulation shows an increase in the speed of the ocean current after entering the tunnel construction, the initial current is 1.5 m/s with the flow area in green, the current speed increases up to 2.6 m/s after entering the tunnel is shown in the flow area in orange and can be seen in the color graph accompanied by the current speed value of each color. Using the continuity equation, which states that the volumetric flow rate must be constant, we can calculate the ratio of the change in cross-sectional area with the equation of the current velocity increasing from 1.5 m/s to 2.6 m/s, the ratio of the cross-sectional area is 1.73. In addition, computational simulations such as Computational Fluid Dynamics (CFD) are used to model and verify the results of theoretical calculations, taking into account the boundary conditions and velocity distributions in the tunnel. This combination of analytical and simulation methods ensures that the increase in ocean current speed is accurately calculated, supporting an effective design for the tunnel system.

The results of the experiment in the study provide data that from the two experiments with different variations in the speed of ocean currents, it can be analyzed that from both there is an increase in the speed of the ocean currents entering the tunnel so that it has the potential to improve the performance of the vertical axis of the ocean current turbine installed in it. This increase in the speed of ocean currents serves as a major driver for turbine performance, as greater kinetic energy can be converted into mechanical energy more efficiently by the vertical axis of the turbine. Thus, the turbine is able to produce a higher energy output. Experimental data also showed that the variation in the speed of ocean currents had a positive correlation with turbine performance, where the higher the current speed, the more optimal the turbine's performance in generating electricity.

3.3 Analysis Results

The results of the tunnel construction data analysis in the form of graphs can be seen in figure 8. This graph provides a comparison of the results of the simulations carried out, the data analyzed includes significant ocean current speeds from both different variations. The appearance of the graph is needed as a way to make it easier to see the results of the simulations carried out by the author.

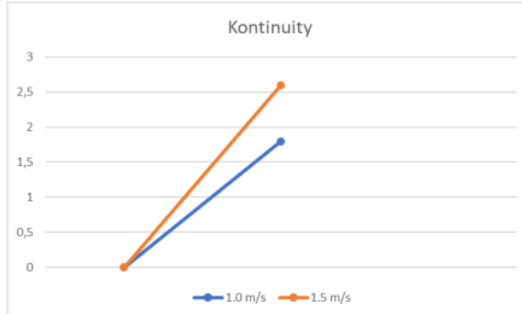

Figure 8. Comparison graph of simulation results

The comparative graph of the results of the two simulations with different variations in ocean current velocity shows an interesting pattern of speed increase. At an ocean current velocity of 1.0 m/s, the increase in velocity indicates a relatively small but significant change. Meanwhile, at an initial ocean current velocity of 1.5 m/s indicates that stronger currents tend to experience greater acceleration. This can be explained by factors such as differences in the thrust generated by stronger currents and the possibility of synergistic effects with other environmental factors.

4. Conclusion

Based on the research and design of vertical axis ocean current turbine tunnel construction, it can be concluded that the tunnel construction designed on the vertical axis ocean current turbine has an influence in increasing the speed of the ocean current entering the tunnel. At the ocean current speed of 1.0 m/s, there is an increase in the current speed of 1.8 m/s, while the ocean current speed of 1.5 m/s has an increase in the current speed of 2.6 m/s, which has the potential to increase the performance of the vertical axis ocean current turbine. Performance of marine turbines is greatly affected by the speed of ocean currents. The strong and stable ocean currents provide greater kinetic energy, allowing the turbine to generate better electrical power.

This study shows that the use of tunnels can make the flow of ocean currents more uniform with a reynold number of 100.250 at a sea current speed of 1.0 m/s and 150.375 at a sea current speed of 1.5 m/s, because the reynold number is less than 2000, it can be concluded that the type of flow contained in the tunnel is a type of laminer fluid flow.

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